Fuzzy Logic On The Frontiers Of Decision Analysis And Expert Systems

H.-J. Zimmermann

RWTH Aachen
Templergraben 55
D-52062 Aachen
Phone: (0241) 80 61 82
Fax: (0241) 88 88-168
E-mail: zi@buggi.or.rwth-aachen.de

Abstract

Decision Analysis and Decision Support is an area in which applications of fuzzy set theory can be found since the early 70's. Still there are areas, such as fuzzy controls, that have gained much wider acceptance in practice than fuzzy decision analysis. This paper tries to describe where fuzzy decision support stands now and what would have to be done to gain wider acceptance. One of the major conclusions is, that experimentation is needed and that empirical work in the engineering area is quite different from empirical work in human decision making. Interdisciplinary team work may be much more important in the latter area than in the former.

Decisions, Decision Support Systems and Expert Systems

Normative vs. Descriptive Decision Theory vs. Connectionistic Views

The meaning of the term 'decision' varies widely. Very often it is used without defining its interpretation and this frequently leads to misinterpretations of statements about decisions. decision analysis or decision support systems. To avoid misunderstandings we shall select from the large number of possible definitions three, which are of particular relevance to this paper:

(a) Decision Logic (formal or normative)
Here a "decision" is defined as an abstract, timeless, contextfree "act of choice", which is best be described as a quintuple D (A, S, E, U, P), where A is the action space, S the state space, E the event space, U the utility space and P the probability space. Often this purely formal model for "rational"decision making is illustrated by examples which suggest a relationship of this model to the reality of decision making, obliterating the fact that decision logic is a purely formal, mathematical or logical theory, focussing on rationality in acts of choice. Nevertheless, this model of a decision underlies many methods for or theories about decision making.

b) Cognitive decision theory
This is an empirical, descriptive, nonstatistical, context related process theory [13] and considers a "decision" as a decision making process very similar to a problem solving process, which is a special, time consuming, context dependent information processing process. The human decision maker is considered in analogy to a computer system, i.e. data and knowledge has to be fed into the system. This and the type of information processing performed determines the outcome [24].

c) The connectionist paradigm
Neural nets also model living (human) information processing, but on a more physical and not so functional level. Information is processed from input via hidden to output layers of artificial neurons. One of the differences between the "cognitive" and the "neural" decision model is, that the latter includes explicitly and even concentrates on learning and on topological features, while the former does not exclude learning but does not consider it as one of the points of major interest.

Decision Support Systems vs. Expert Systems

Decision Support Systems (DSS), as successors of Management Information Systems (MIS),traditionally follow the decision logic line of thinking and include in MIS algorithmic tools to improve the choice activity of decision makers. This includes optimization methods, mathematical programming, multi criteria models etc.

They are "structure related", normally assume that the decision problem can be formulated mathematically and do not stress information processing and display.

By contrast to DSS, Expert System (ES) or knowledge-based systems, as successors of the "General Problem Solver" [13] follow more the process paradigm of cognitive decision theory; they not necessarily assume that the decision problems can be formulated as mathematical models: they substitute human expertise for missing efficient algorithms and they are not structure- but context related, with much smaller domains of application than DSS. "Knowledge" is represented in many different ways, such as, frames, semantic nets, rules etc. Knowledge is processed in inference machines, which normally perform symbol processing, i.e. truth values of antecedents, conclusions etc. A point to which we will return later in this paper.

In the more recent past the border between DSS and ES has become pretty fuzzy. Some experts consider ES as part of DSS [19], others see DSS and ES as basically different systems and others combine the two approaches into "Knowledge-based DSS" [11]. Even though all of these systems can support decisions in one or the other way, for the sake of argument I shall keep the distinction between algorithmic DSS and Knowledge-based ES.

Scientific Background

As already mentioned above, "decision" is regarded differently in different decision theories; and, furthermore, different sciences are contributing to decision making paradigms. This fact will be important for the conclusions drawn at the end of this paper. Therefore, figure I sketches some of the relationships.

Main Deficiencies of DSS

Let us consider DSS in the broad sense as the application oriented result of decision analysis and consider some of their deficiencies, which are relevant for the interface with "Fuzzy Logic": DSS and ES-technology share the dichotomy character, which leads, however, to different weaknesses on either side. While on the DSS side models and algorithms become sometimes pretty bad approximations of real problems, on the ES-side this leads to symbol processing rather than to knowledge processing. The former might be much harder to detect than the latter. Both, DSS and ES share the suffering from the size of realistic problems: nowadays there is often an abundance of data rather than a lack of them.

Both areas are influenced by the discrepancy between demand and supply: while scientific contributions normally are very specific, i.e. developed in one scientific discipline and focussing on one (small) and imagined problem, the practitioner on the demand side is looking for tools and solutions to his problems, which are frequently multi disciplinary, and not for approaches that solve a part of his problem, probably even impairing other parts. This is more serious for DSS than for ES, because the latter generally have a much smaller domain of application. This and some other factors often impair userfriendliness and. hence, user acceptance to a degree that the use of the tools never really occurs.

Is "Fuzzy Logic" a Fuzzy "Logic"?

Formal Science vs. Technology

The generic term "Fuzzy Logic" for the entire area of fuzzy set theory and fuzzy technology is mainly misleading: it suggests that, at least to newcomers and many practitioners, it is a formal theory like dual logic and tempts people to fall into the same trap as, for instance, often decision logic, namely to use formal terms and reasoning procedures and interpreting them as descriptions of parts of reality. The use of fuzzy sets in a formal way is certainly legitimate in mathematics, in fuzzy logic in the narrow sense, in decision logic. But it is not always appropriate in decision analysis used as a decision technology.

As shown in figure I, formal sciences have contributed considerably to decision logic. The same is true for "Fuzzy Logic": considerable work has been done during the last decade with respect to preference modeling [6], multi-criteria decision making [24], fuzzy mathematical programming, etc. In this respect the contribution of FL to decision analysis is at least as large as that to Fuzzy Control (FC). As will be shown later, however, decision analysis lacks behind FC with respect to technology.

Fuzzy Logic and its Tools

"Tools" can be interpreted in at least two ways: concepts such as "linguistic variables", "fuzzy clustering", "fuzzy AHP", etc. can, of course, be considered as tools of Fuzzy Set Theory to solve problems of decision analysis, data mining, etc. For the sake of clarity we will call them concepts and methods and reserve the term tools for hardware or software products in DSS or ES. Strictly speaking one could distinguish between decision analysis (DA) and decision support (DS). In this case DA could still be considered to be part of the theory and DS would primarily belong to applications and technology. Since these terms are very often used synonymously, we shall not make this distinction but rather state, that concepts and methods (of which there are plenty) are necessary conditions for useful applications, but that "tools" in the sense defined above are also necessary for efficient and attractive real applications in DS. Neither concepts nor tools are, however, sufficient conditions, for user acceptance.

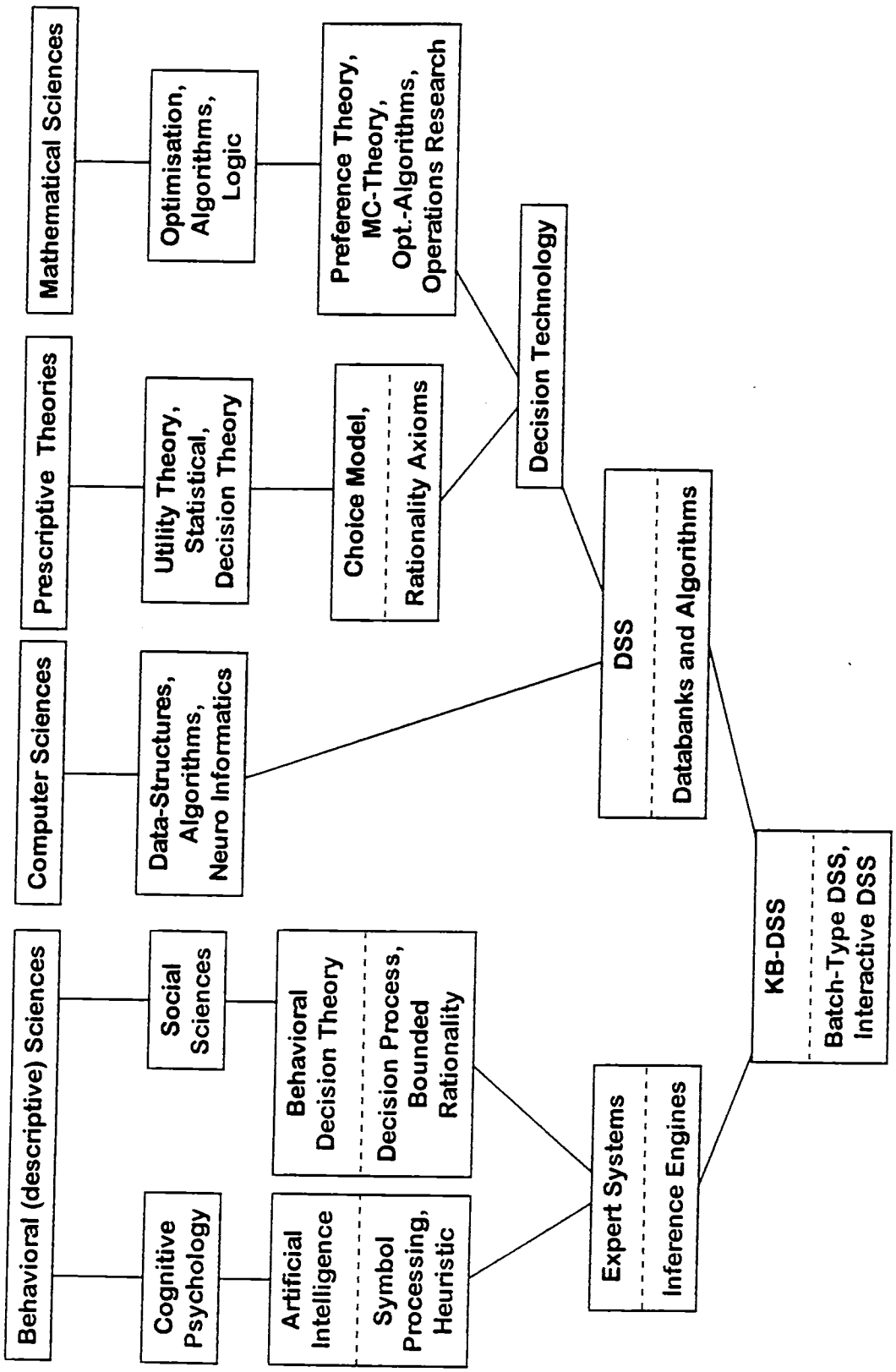
Behavioral (descriptive) Sciences
Cognitive Psychology
Social Sciences
Artificial Intelligence
Symbol Processing, Heuristic
Behavioral Decision Theory
Decision Process, Bounded Rationality
Computer Sciences
Data-Structures, Algorithms, Neuro Informatics
Prescriptive Theories
Utility Theory, Statistical, Decision Theory
Choice Model,
Rationality Axioms
Mathematical Sciences
Optimisation, Algorithms, Logic
Preference Theory, MC-Theory, Opt.-Algorithms, Operations Research
Decision Technology
DSS
Databanks and Algorithms
Expert Systems
Inference Engines
KB-DSS
Batch-Type DSS, Interactive DSS

Figure 1

Fuzzy Sets, Neural Nets, Genetic Algorithms

Even though this paper is only about "Fuzzy Logic", nowadays it is impossible to talk about FL without also referring to neural nets, genetic algorithms, evolutionary computing, soft computing or computational intelligence. It would certainly exceed the scope of this paper to comment in detail on the interrelationship of these areas. In decision analysis and decision support the extension of FL to computational intelligence has just started, but a strong development in this direction is desirable and expected.

The Frontiers of Fuzzy Decision Analysis

Available Tools

In terms of "concepts and methods" fuzzy set theory offers many more tools than are being used in decision analysis. Partly they are relaxations of classical dichotomous methods, such as fuzzy clustery, fuzzy regression methods, fuzzy mathematical programming. Partly they consist of new concepts of reasoning, that take "classical" inference machines of ES from symbol processing to meaning preserving reasoning. Fuzzy databank technology [15] or fuzzy query languages may have to be considered as new techniques rather than the relaxation of classical databank management.

Not quite as rich as the 'concepts' area is the variety of tools in the sense of software or hardware products: apart from some axiomaticly justified Expert System shells [1] there exist numerous hardware [17] and even more software tools for fuzzy controllers, which are sometimes called "Expert System Shells". They are certainly extremely useful for applications of Fuzzy Control. Most of them, however, do not contain modules which are essential for ES: Linguistic Approximation, Inference Engines that model in a verified way the reasoning of decision analysts, interfaces to databanks, data mining facilities etc. Also they use almost exclusively knowledge based approaches and hardly any of the available fuzzified methods, for example fuzzy mathematical programming modules, which are extensively used in managerial decision making.

There is also another reason why fuzzy technology has not yet penetrated decision support as much as engineering control: fuzzy controllers are often smaller stand alone systems. Managerial Decision Support Systems are generally large, rather complex, software systems into which fuzzy technology would have to be integrated at appropriate points, well understood by the developing software engineers. This has not yet been achieved on a larger scale.

Deficiencies of 'Fuzzy Logic ' for Decision Support

A fuzzy controller can be calibrated and optimized by observing the behavior of the system and experimentally determining the most appropriate parameters of the controller.

In decision analysis and decision support this is generally not possible. Systems are too complex to be modelled completely and adequately. It is very hard - if at all possible - to determine whether a model really describes the real system or not and whether an optimal solution to the - may be thousand-dimensional - model is also optimal for the real problem. Also by contrast to engineering control the quality of a decision might only become known after a very long time - maybe after decades in strategic planning. The quality of a decision support system is, therefore, determined by the degree to which it supports the modelling and/or decision making of the user. For the algorithmic part of such a system fuzzified normative tools might be quite appropriate: one should, however, realize, that models of (normative) decision analysis are generally context free. Decision support tools, by contrast, have to be context dependent. Experience or suggestions, for instance, which operators to use in personnel planning systems by contrast to production scheduling, are not yet available, but would be as useful for decision makers as the existence of well-known standard distribution functions for the statistician.

An implicit convention in (fuzzy) multi criteria analysis seems to be, that methods that solve such problems are the better the more discriminatory they are. Tong and Bonissone [18] dispute this convention and ask for stability and userfriendliness rather than high discriminatory power. Unluckily their work has - to my mind - been recognized too little and research in this direction might increase appreciation of fuzzy decision analysis tools by decision makers considerably - even if the mathematical and computational effort (in the computer) would also increase.

For the knowledge-based part the quality is determined by the degree to which the user, decision maker or expert is modeled by the system. This requires in addition to good software engineering empirically verified inference systems. And this in turn requires still more research in which formal and empirical disciplines join their strengths. Experience has shown, that this type of research [2] [27] is expensive, time consuming and normally requires research teams in which psychologists are part as well as formal scientists and probably also computer scientists and decision analysts. The big future challenge for fuzzy technology with respect to decision analysis and support seems to me, to develop empirically verified and efficient calculi of fuzzy rules - rather than advance fuzzy logic in the sense of an extended logic. This could very well go in die direction of "computing with words" which has been suggested by Prof. Zadeh in the recent past.

Future (desirable) Developments

As already mentioned above, a considerable body of formal methodological fuzzy concepts and method for decision analysis exists already. If "Fuzzy Decision Analysis" is to become as well-known and accepted as fuzzy control, a number of further advances will have to be achieved:

1. The already existing integration of Fuzzy Technology with Neural Nets and possibly other - traditional - concepts will have to be advanced in order to increase learning and adaptation capabilities.

2. More interdisciplinary research, including empirical behavioral work will have to be performed in order to obtain context-dependent knowledge and experience. This may lead into the direction of establishing a "calculus of fuzzy rules", independent from formal reasoning systems, and to userfriendly concepts, such as proposed by Tong and Bonissone [18].

3. An integration of these concepts into existing decision support systems, using modern software engineering technology, will provide possibilities not only to work in laboratory-type research but to obtain experience - and acceptance, by wider spread field study type applications.

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